Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia

STATISTICAL ANALYSIS OF SEAWATER BALLAST TANK CORROSION DATA

Norhazilan Md Noor
Nordin Yahaya
Fakulti Kejuruteraan Awam
Universiti Teknologi Malaysia
81310 Skudai, Johor

ABSTRACT: High variability of corrosion wastage has been acknowledged as a factor that contributes to the uncertainties in corrosion assessment. Hence, statistical analysis on a collection of corrosion measurements seems to be one of the best options to express corrosion rates appropriately. This paper demonstrates an alternative approach to analysing corrosion data randomly collected from seawater ballast tank structure. A statistical time-dependent corrosion depth model is proposed in this paper to improve corrosion interpretation. The new statistical model can be used to predict the likely variation of corrosion depth at any point of time/ age of the vessel. The proposed model intends to simplify the modelling process so the available data can be fully utilised for prediction purposes.

Keywords: Corrosion, assessment, statistic, ballast tank, vessel

1. CORROSION OF SHIP STRUCTURES

Problems arising from corrosion are considered to be among the most important age related factors affecting structural degradation of ships in complex seawater environments. Seawater properties such as oxygen content, salinity, temperature, pH level, and chemistry can vary according to site location and water depth, making it difficult to predict the corrosion progress. Statistics for ship hulls show that 90% of ship failures are attributed to corrosion [Melchers, 1999]. Localised corrosion especially pitting, is among the major types of physical defects found largely on ship structures. The areas of the ship most exposed to corrosion are wing ballast tanks, resulting from exposure of seawater, humidity, and salty environment when empty.

The corrosion damage of steel structures in ships is influenced by many factors, including the corrosion protection system (coating and inhibitor) and various operational parameters. The operational parameters include maintenance, repair, percentage of time in ballast, frequency of tank cleaning, temperature profiles, use of heating coils, humidity conditions, water and sludge accumulation, microbial contamination, composition of inert gas, etc. To date, rigorous work to understand the effect of many of these factors and their interactions is lacking in the case of ship structures [Paik and Thayambali, 2002]. Moreover there are limited research and corrosion measurement data available for corrosion rates in tankers [Wang *et al*., 2003]. Discussions on corrosion wastage still remain largely qualitative rather than quantitative [Wang *et al*., 2003].

2. SEAWATER BALLAST TANK CORROSION DATA

Paik [2004] originally collected the corrosion data of seawater ballast tank used in this research by using ultrasonic device. The data was grouped by the age of the ship and defect depth variation as presented in Table 1. The estimation of corrosion growth rate based on the metal loss volume is not possible for each vessel since only one set of data available from the inspection activities. The only way to estimate corrosion rate linearly is by assuming the corrosion-initiation time; the time when corrosion start to occur due to the resistance given by the coating protection system. Normally, this deterministic model is assumed valid for all vessels even though, in reality, each ship involved in the sample has different factors that affect the corrosion progress. An enhancement to the original deterministic model as proposed by Paik and Thayambali [2001], Paik [2004] and Paik *et al*. [2004] is proposed in this paper to incorporate the variation of the corrosion data.

The works by Paik and Thayambali [2001], Paik [2004] and Paik *et al*. [2004] have been revised with the introduction of a statistical model for a time-dependent corrosion process based on the same corrosion data. In this section, an Exponential model is proposed with the intention of minimising the effects of uncertainties caused by the scattered corrosion data.

Table 1: Gathered number of measured data set of thickness loss due to corrosion in seawater ballast tanks of bulk carriers [Paik and Thayambali, 2001].

Time (year)-middle class	**Depth of corrosion (middle class)**							
	0.25	**0.75**	**1.25**	**1.75**	**2.25**	**2.75**	**3.25**	**3.75**
11.25	2	0	0	0	0	0	0	0
11.75	18	5	0	0	0	0	0	0
12.25	6	3	9	0	0	0	0	0
12.75	23	2	0	0	0	0	0	0
13.25	16	26	30	2	0	0	0	0
13.75	9	0	0	0	0	0	0	0
14.25	3	3	0	0	0	0	0	0
14.75	1	2	0	0	0	0	0	0
15.25	22	13	10	3	2	0	0	0
15.75	9	1	0	0	0	0	0	0
16.25	5	0	0	0	0	0	0	0
16.75	12	8	5	2	1	1	0	0
17.25	19	1	0	0	0	0	0	0
17.75	84	1	2	4	0	0	0	0
18.25	34	26	37	9	4	3	0	0
18.75	1	0	2	0	0	0	0	0
19.25	52	10	5	8	6	1	0	1
19.75	84	9	1	0	2	0	0	0
20.25	165	29	9	1	0	0	0	0
20.75	10	14	11	10	16	2	0	0
21.25	69	42	11	7	2	4	0	0
21.75	9	1	1	2	2	0	0	0
22.25	3	5	0	0	0	0	0	0
22.75	8	18	1	3	0	0	0	0
23.25	31	13	4	1	0	0	0	0
23.75	8	3	1	0	0	0	0	0
24.25	7	11	7	2	0	0	0	0
24.75	18	15	2	0	0	0	0	0
25.25	30	49	48	57	40	2	2	1
25.75	10	1	1	2	0	0	0	2
26.25	8	8	1	0	0	0	0	0
26.75	0	7	1	0	0	0	0	0

2.1 Linear regression model

An average value and standard deviation of corrosion depth is estimated individually for each set of ship age. The graphs of average and standard deviation value have been plotted against ship age to establish a relationship between the progress of averaged metal loss and the vessel age. The regression analysis was used to re-scale the data to time $t=0$. From Figures 1 and 2, it seems the averaged metal loss is scattered over the time but there is some indication of the increment of the averaged depth and standard deviation over time. The linear increment can be expressed as a function of time by using the regression equations as follows:

$$d_{ave} = 0.0251.t_v + 0.1511 \qquad \text{Equation 1}$$

$$std_d = 0.0232.t_v - 0.037 \qquad \text{Equation 2}$$

where:

d_{ave} = linear regression model of defect depth average
std_d = linear regression model of defect depth standard deviation
t_v = age of vessel (year)

2.2 Probability time-dependent model

The linear regression equation is likely to contain some errors owing to the large scatters of averaged corrosion depth of each vessel age group. To minimise the errors, this deterministic equation will be combined with a probability distribution of corrosion depth representing all of the data. The next step is to construct a distribution for all the data by removing the effects of time. This distribution of the entire data was found to be best reproduced by the Weibull distribution based on linear fitting of the probability plot and verified by Chi-square goodness-of-fit test. Figure 3 shows the histogram of all the data and Figure 4 demonstrates the Weibull probability plot of all of the data. The Weibull distribution function for the data can be expressed as follows:

$$f(x_d) = \frac{1.1(x_d)^{0.1}}{1.27^{1.1}} \exp\left[-\left(\frac{x_d}{1.27}\right)^{1.1}\right] \qquad \text{Equation 3}$$

where:

x_d = corrosion depth

The shape parameter for the Weibull distribution was found to be 1.1, and adequate accuracy was mentioned by approximating to an Exponential distribution. Statistically, when shape parameter, $\beta=1$, the Weibull distribution is identical to Exponential distribution. The function of the whole can be rewritten as follows:

$$f(x_d) = \lambda.\exp[-x_d\lambda] \qquad \text{Equation 4}$$

This distribution no longer represents the corrosion progress in time since this effect has been removed by gathering all of the data under one distribution. Nevertheless, λ has a direct relation to the mean value of corrosion depth as defined by Equation 5. This can then be incorporated into the Exponential function to produce a time-dependent distribution.

$$\lambda = \frac{1}{d_{ave}} \qquad \text{Equation 5}$$

By inserting the linear regression equation into Equation 5, the new expression of Exponential distribution parameters can be written as:

$$\lambda = \frac{1}{0.0251.t_v + 0.1511} \qquad \text{Equation 6}$$

Equation 4 then can be rewritten as follows:

$$f(x_d) = \frac{1}{0.0251.t_v + 0.1511}.\exp\left[\frac{-x}{0.0251.t_v + 0.1511}\right] \qquad \text{Equation 7}$$

This function now can be used to predict the distribution of corrosion depth at any point of time after the insertion of the linear function of averaged corrosion depth. However, there are two factors, which might affect the accuracy of corrosion depth prediction even though the effect might be small. However, the proposed models can be continually verified to improve its reliability when new data from the latest inspection becomes available. The two factors are as follows;

1. If the distribution of corrosion depth better suits the Weibull distribution when the shape parameters β>1, then the change of distribution shape from Weibull to Exponential for the sake of simplicity might affect the accuracy of the prediction.
2. There is a significant increment of standard deviation value of corrosion depth in time as portrayed in Figure 2. The insertion of a linear function for the averaged corrosion depth might contribute to the increment of corrosion depth variation over time. The longer the prediction, the higher the variation of corrosion depth in the future that might mislead the assessment results.

2.3 Prediction result

Four sets of corrosion data were generated by the using simulation and inverse transformation method for comparison purposes. The proposed Exponential time-dependent model was used to produce distribution of corrosion data for vessel age of 18-18.5 years, 20-20.5 years, and 21-21.5 years old. These age groups were chosen due to high number of data collected during on site inspection. The generated data was then compared with the measured data in the same vessel age group. Based on the comparison of histogram shown by Figures 5 to 7, it is clearly shown that the Exponential distribution yields better prediction results for age groups of 20-20.5 years and 21-21.5 years. Overall, the proposed model has overcome the problem of identifying the exact value of corrosion initiation time to enable the linear estimation of corrosion growth rate. The prediction results show that the Exponential time-dependent corrosion model is quite reliable in predicting the future distribution of corrosion depth. The model could be improved if more data can be measured on site.

3. CONCLUDING REMARKS

This paper has demonstrated an alternative approach to analysing corrosion data randomly collected from a large number of like assets (in this case vessel ballast tanks). Rather than making an assumption on the time to the start of the corrosion process and then develop a linear model of corrosion rate as normally practised, a corrosion depth model which are a function of time have been proposed. The new model can be used to predict the likely variation of corrosion depth at any point of time without having to estimate the corrosion growth rate. The provided information from the vessel inspection is full of uncertainties owing to the nature of marine corrosion. The proposed model intends to simplify the modelling process so the available data can be fully utilised for prediction purposes. If more information can be revealed, the prediction model could be improved to achieve a high accuracy of depth prediction at any point of time.

4. REFERENCES

Melchers R.E. (1999a), *Corrosion Modelling for Steel Structures*, Journal of Constructional Steel Research, **52**, pp. 3-19.

Paik J.K. (2004), *Corrosion Analysis of Seawater Ballast Tank Structures*, International Journal of Maritime Engineering, **Vol. 146**, Part A1, pp.1-12.

Paik J.K. and Thayamballi A.K. (2002), *Ultimate Strength of Ageing Ships*, Journal Engineering for the Maritime Environment, **Vol. 216**, pp. 57-77.

Paik J.K, Thayambali A.K., Park Y.I. (2004), *A Time-dependent Corrosion Wastage Model for Seawater Ballast Tank Structures of Ships*, Corrosion Science, **Vol.46**, Issue 2, pp.471-486.

Wang G., Spencer J., Elsayed T. (2003), Estimation of Corrosion Rates of Structural Members in Oil Tankers, Proceedings of OMAE 2003, 22nd International Conference on Offshore Mechanics and Arctic Engineering, Cancun, Mexico

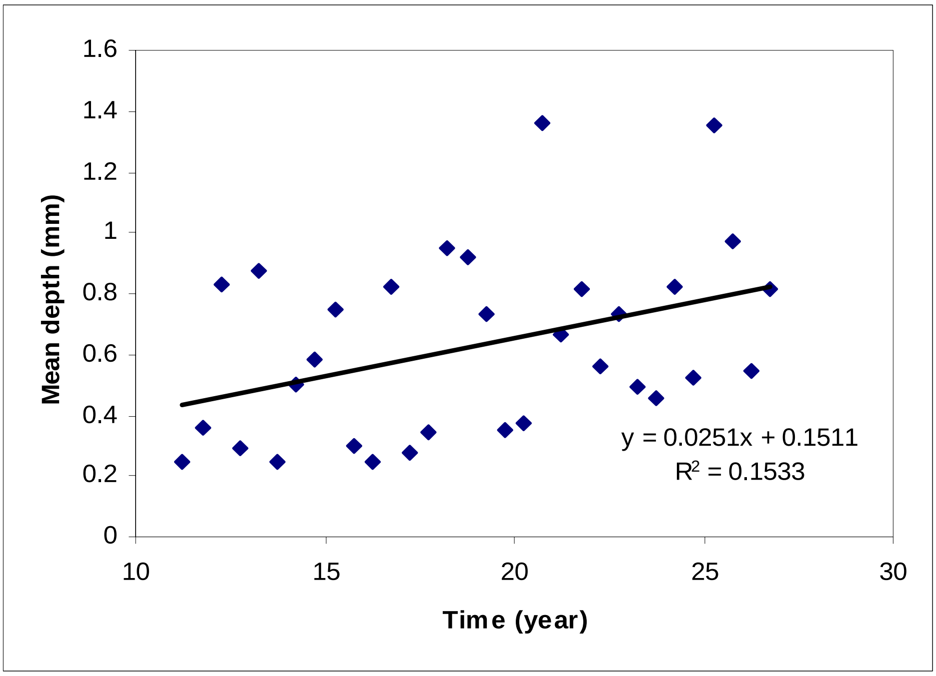

Figure 1: Linear regression analysis of depth averages and vessel age

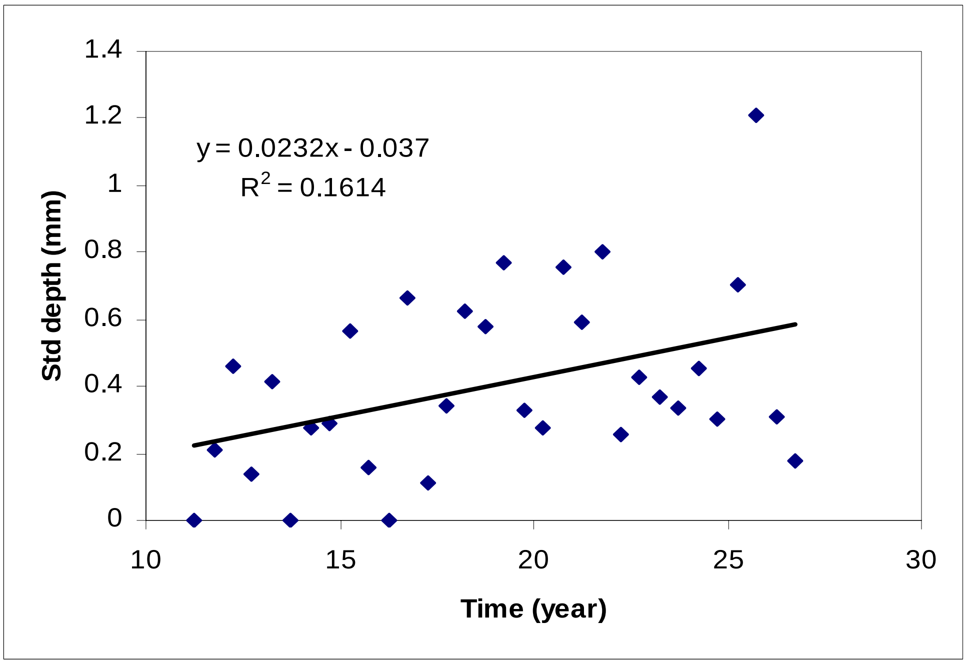

Figure 2: Linear regression analysis of depth standard deviation and vessel age

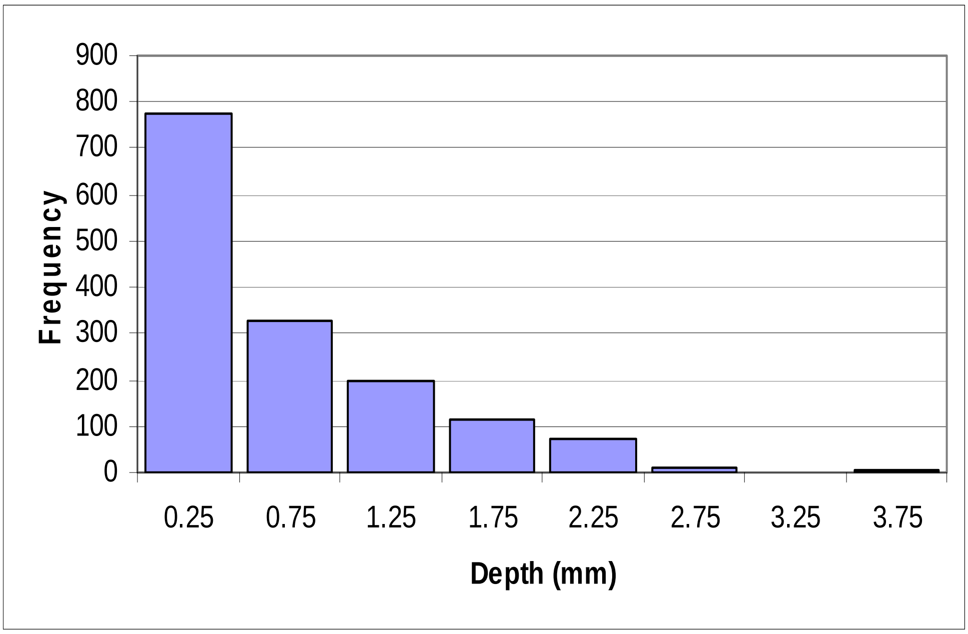

Figure 3: The histogram of the whole set of corrosion depth

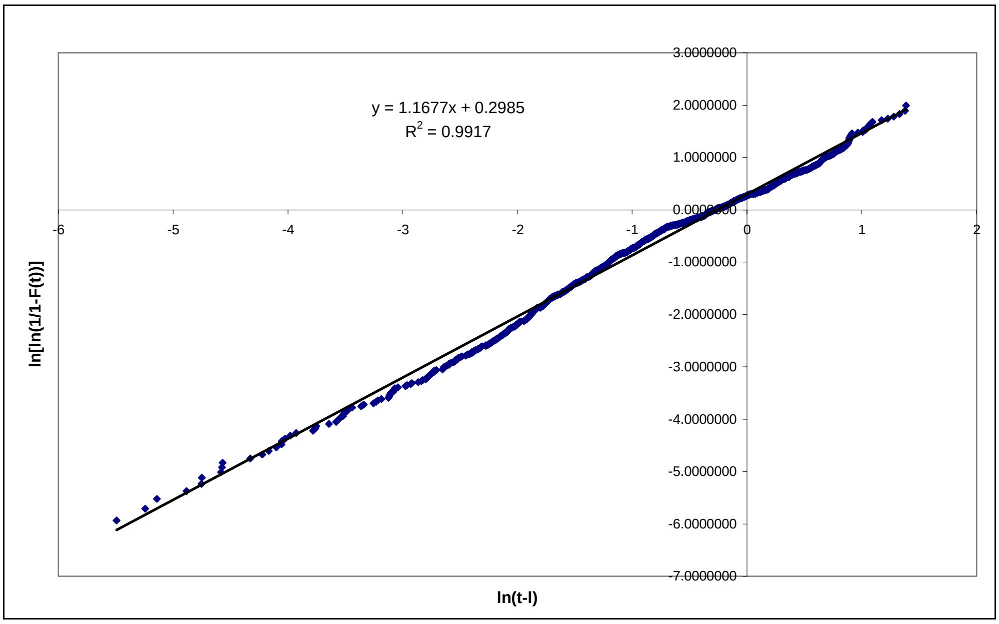

Figure 4: The Weibull probability plot of measured data (actual data)

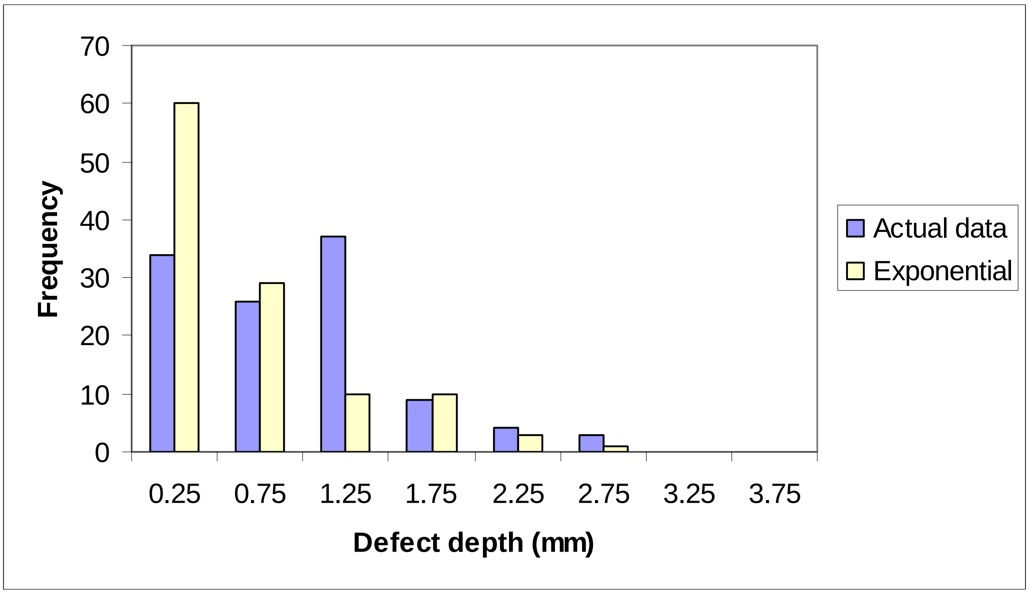

Figure 5: Comparison of predicted depth data for vessel age of 18-18.5 years old

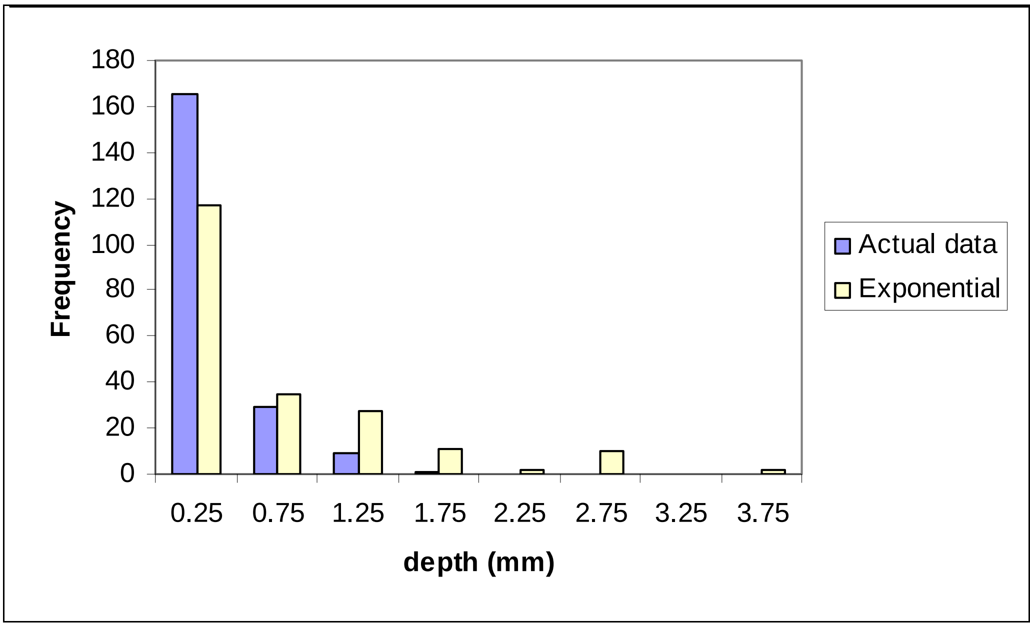

Figure 6: Comparison of predicted depth data for vessel age of 20-20.5 years old

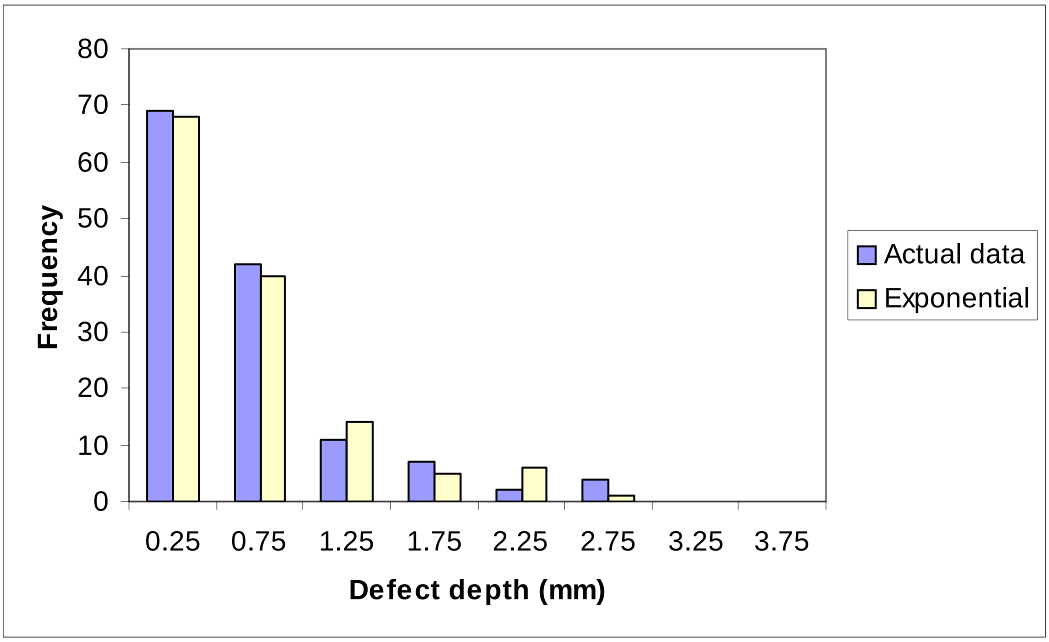

Figure 7: Comparison of predicted depth data for vessel age of 21-21.5 years old